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Assessment of air quality in Stockholm by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke

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Abstract

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Exposure to respirable suspended particles (RSP) from all sources and environmental tobacco smoke (ETS) was assessed for 190 nonsmokers in Stockholm during 1994. Each subject wore a personal monitor for 24-h, provided saliva samples for cotinine analysis, and completed a detailed questionnaire about air quality and life-style.

The subjects consisted of housewives and househusbands in one main group and working men and women in the second. The housewives and househusbands wore a single monitor throughout the 24-h period and the working subjects wore one monitor at work and a separate monitor while not at work. The geodemographic distribution of the recruited subjects accurately reflected the population of Stockholm.

For most of the subjects, exposure to ETS and nicotine was at or below the limits of quantification (LOQ). This finding was supported by the fact that about 80% of the recruited subjects claimed that their exposure to ETS was "none" or "low."

The concentration of RSP was found to be highest (median 39 $\mu g \cdot m^{-3}$) in homes where smoking occurred and below the LOQ in the workplace irrespective of its smoking status. These levels are at the lowest end of typical indoor air levels for RSP.

For the housewives and househusbands living in smoking homes (nonsmoking homes in parentheses), the median exposure levels were 39 $\mu g \cdot m^{-3}$ (18 $\mu g \cdot m^{-3}$) for RSP, 17 $\mu g \cdot m^{-3}$ (0.12 $\mu g \cdot m^{-3}$) for ETS particles, and 1.1 $\mu g \cdot m^{-3}$ (0.05 $\mu g \cdot m^{-3}$) for nicotine. Both the pre- and postmonitoring cotinine saliva levels measured for these housewives and househusbands were 2.9 $ng \cdot ml^{-1}$ (pre- 0.56 $ng \cdot ml^{-1}$, post- 0.41 $ng \cdot ml^{-1}$). The highest exposure levels were recorded for the housewives and househusbands in the age range of 35—49 years.

For the working subjects, the exposure measured in smoking workplaces (nonsmoking workplaces in parentheses) gave median levels of 16 $\mu g \cdot m^{-3}$ (16 $\mu g \cdot m^{-3}$) for RSP, 1.1 $\mu g \cdot m^{-3}$ (0.42 $\mu g \cdot m^{-3}$) for ETS particles and 0.2 $\mu g \cdot m^{-3}$ (0.15 $\mu g \cdot m^{-3}$) for nicotine. Similarly measured exposures at home (nonsmoking homes in parentheses), including all other locations outside the workplace, gave median levels of 24 $\mu g \cdot m^{-3}$ (19 $\mu g \cdot m^{-3}$) for RSP, 1.4 $\mu g \cdot m^{-3}$ (0.2 $\mu g \cdot m^{-3}$) for ETS particles, and 0.15 $\mu g \cdot m^{-3}$ (0.07 $\mu g \cdot m^{-3}$) for nicotine.

Overall, the exposure levels of ETS due to living with smokers in Stockholm was found to be much lower than similar exposures measured previously in the United Kingdom and the United States. Over 70% of all the nicotine measurements and 60% of all the ETS measurements were below the LOQ. When the median values for nicotine and ETS particles are converted to cigarette equivalents, Stockholm housewives and househusbands living with smokers would receive 6—9 cigarette equivalents per year, working nonsmokers living with smokers would receive 0.6—0.7 cigarette equivalents at home, and nonsmokers working with smokers would be exposed to 0.1—0.2 cigarette equivalents at work. The exposures were therefore up to six times greater at home than in workplaces where smoking was occurring.

Although all the subjects were recruited as nonsmokers on the basis of their self-reported nonsmoking status, saliva cotinine measurements were used for confirmation. Subjects with cotinine levels below 25 $ng \cdot ml^{-1}$ were considered to be nonsmokers although the selection of a threshold level within the range of 10—50 $ng \cdot ml^{-1}$ was not considered to be critical. With a threshold of 25 $ng \cdot ml^{-1}$, between

2.7% and 5.3% were later shown to be misclassified as nonsmokers, depending on the definition of misclassification used.

During the study period the air quality in Stockholm could be described according to British nomenclature as "very good" for the majority of the time. The daily average at no time fell below "good," and the maximum hourly nitrogen dioxide level was 111 $\mu g \cdot m^{-3}$ (inner city at street level) on the coldest day (average −0.2°C).

Introduction

Indoor air quality has assumed increasing importance, especially in the workplace and home, environmental tobacco smoke (ETS) and its many claimed health effects continuing to be highlighted (1, 2). In the United States the Occupational Safety and Health Administration (OSHA) is proposing regulations for employees working indoors in nonindustrial environments to protect them from ETS (3).

On mainland Europe, Stockholm was the first major city in a series being studied for air quality, with specific reference, but not limited to, the assessment of exposure to ETS. Respirable suspended particulate (RSP) matter was also measured. This study does not attempt to assess the physicochemical properties of RSP, but it is a mixture of materials consisting of, for example, soot, smoke, mineral dust, and human dust.

The measurement of RSP is important in relation to ETS exposure since ETS can be one of its major components and advances in determining ETS constituents and their subsequent contribution to indoor air are still continuing. ETS is considered, by authorities, to be a significant component of indoor air pollution, and as such it can cause occupant discomfort and possibly acute illness. Other examples of contamination include halogenated solvents, carbon dioxide, and petroleum products.

There are materials of greater risk that may pose a cancer threat when found in indoor air. Gold et al (4) listed asbestos, radon 222, ETS, heavy metals, and a wide variety of organic compounds. Specifically targeted to be of concern are compounds that include polyaromatic hydrocarbons, dichloromethane, benzene, formaldehyde, certain pesticides, N-nitrosamines, and cadmium and nickel compounds. O'Neil et al (5) have published methods for analyzing many environmental carcinogens. ETS may be a source of these carcinogens, but a major contribution to the contamination of indoor air clearly comes from components present in outdoor air.

In this study we have specifically chosen to examine ETS and RSP, but for future studies samplers for collecting volatile organic compounds are being devised.

Several markers for ETS have been proposed, including RSP and carbon monoxide. Until the mid-1980s carbon monoxide was in common use (6), but there are many other sources of this compound and its usefulness is questionable. A sensible and obvious marker of choice should be nicotine, but its behavioral characteristics compared with other vapor phase constituents of ETS limit its use (7, 8, 9). Nicotine was used in this study mainly for comparison with other methods of assessing ETS exposure, and it was collected on a polymer resin prior to analysis (10).

RSP were collected by use of a cyclone separator fitted upstream from the filter assembly (11), and the weight of particulate matter was estimated gravimetrically (12).

The importance of objective personal monitoring measurements of ETS in relation to air quality has been cited previously (13, 14). In this study personal monitoring was undertaken over a 24-h period in combination with the self-reporting of activities using diaries and questionnaires, only subjects claiming to be nonsmokers being used.

To aid the comparison of exposures at home and at work, the choice of subjects for participation in this study was made from housewives and working men and women. Furthermore, whether the households and workplaces of the participants were smoking or nonsmoking was a major consideration. An improvement over the British study conducted in Leeds, England, by Phillips et al (14) is that the working volunteers wore one monitor while at work and a separate monitor at all other times. This procedure enabled a more accurate exposure assessment than the wearing of just one monitor.

The method for selecting volunteers was given careful consideration in order to make genuine and valid comparisons of exposures throughout Europe possible. A segmentation system called Mosaic (CCN Marketing, Nottingham, England) was used. Mosaic was chosen as it is Europe's leading geodemographic system.

Weather conditions and information on other pollutants affecting air quality in the city of Stockholm during the study were provided by the City of Stockholm authorities.

In this report we have made some comparison of the levels of ETS and nicotine exposure determined with the yield of a typical Swedish cigarette, expressed in terms of cigarette equivalents (CE). The term cigarette equivalent has been used previously (15) to put the possible exposure of humans breathing ETS over time into context with a potential amount of ETS inhaled from a specified cigarette type.

The misreporting of smoking status (misclassification) has also been estimated in this study. Various rejection criteria for estimating misclassification have been compared by Etzel (16), but the criteria that have been selected for use were the same as those used previously by Phillips et al (14).

Subjects and methods

Recruitment of subjects

Mosaic system

Mosaic is a computerized neighborhood classification system developed by CCN Nottingham England. The method used is known as iterative location and is based on a minimum sum of squares or the "K" squared criterion.

In Sweden the classification was built on a cluster analysis based on 65 sociodemographic variables taken from the Swedish census. The variables included education, income, housing, employment, age, and car ownership. For Sweden it was possible to make a sample based on a register containing every Swede, thus ensuring high validity. Consumer research from leading Swedish research organizations was used to improve the constitution of the 30 Swedish Mosaic types further.

EuroMosaic

For countries in Europe covered by Mosaic there is an additional classification called EuroMosaic. Future air quality studies conducted in these countries can therefore be compared, at a later stage, using EuroMosaic. A detailed insight into the use of Mosaic and EuroMosaic during the course of this and subsequent studies will be the subject of a separate publication.

Sample population from Stockholm

For this air quality study the 30 Mosaic types were combined and represented by 10 Mosaic groups. The sample selected was chosen with the following limitations:

- All subjects to be living within 15 km of the city center of Stockholm
- A third to be in each of the three age groups 20—34, 35—49, and 50—64 years
- Equal percentage distribution into Mosaic groups as for the population 15 km from the center of the city.

Table 1. Cell categorization by home and workplace status.

Cell number	Study type	Smoking status	
		Home	Work
1	Single monitor	Smoking	—
2	Single monitor	Nonsmoking	—
3	Dual monitor	Smoking	Smoking
4	Dual monitor	Smoking	Nonsmoking
5	Dual monitor	Nonsmoking	Smoking
6	Dual monitor	Nonsmoking	Nonsmoking

The Mosaic classification enabled us to study and compare participants with the Stockholm population, using randomly selected telephone numbers from the files created according to the preceding criteria.

Initially the subjects were contacted by SIFO, the largest opinion research bureau in Scandinavia, using the Mosaic files provided by Marknads Analys (CCN affiliates in Sweden). The contact was by telephone screening in which prospective volunteers were asked "Are you 20 to 64 years of age and a nonsmoker?" If they answered "yes," they were asked if they were prepared to participate in a general air quality survey. Suitable volunteers were then screened further over the telephone and queried concerning their previous smoking status, other nicotine product use, and employment status. Emphasis was placed on normal behavior while participating in this air quality study. With the use of this sequence, recruited subjects were assigned to one of six categories (cells) for investigation (table 1). Cells 1 and 2 were intended for housewives and therefore for subjects who did not work, and cells 3 to 6 were for employed subjects, office or nonindustrial workers being specifically targeted.

Suitable volunteers were then given an appointment to attend a combined information and training session organized at the World Trade Center in Stockholm. On arrival, the subjects were shown an instructional video in Swedish which explained the objective of the air quality study. They were also given instructions on how to complete the documentation by a registered nurse from the Karolinska Institute, Huddinge University Hospital, who was experienced in clinical trials. Detailed instructions on how to operate the monitoring equipment were also provided with the help of a demonstration of how to wear the monitor. Each subject was then asked to complete a "first-visit" questionnaire which provided lifestyle information and details of their home (and work, if employed) environment. Questions concerning smoking history, similar to those asked in the screening questionnaire, were also included to verify the validity of subject participation. The subjects were then required to provide a saliva sample (presample) prior to being issued the personal monitors for their 24-h sampling sessions. These sessions commenced on the morning of the following day. All the monitors and study documentation were provided for the subjects in an easy-to-carry sports bag.

The information given to the participants emphasized overall air pollutants, including RSP and ETS, in order that they should not change their habits and therefore would behave normally. The study was approved by the

local ethical committee of the Huddinge University Hospital.

Monitoring session

Air sampling was performed over a 24-h period either using a single personal monitor for the entire duration (single monitor study) or using two personal monitors sequentially over the same period (dual monitor study). All the monitors were fitted with electronic timers to provide an accurate record of the duration of the air sampling. The monitor flow rates were measured before and after each monitoring session to ensure that the sampling rates were consistent over the entire monitoring period. Each subject was asked to complete an activity diary over the 24-h period and to record observations of general air quality, including the presence of tobacco smoke.

Home study — "housewife" assessment

The nonworking subjects recruited for participation in cells 1 and 2 were provided with a single personal monitor. At the start of the monitoring period, the subjects were required to switch the monitor on and subsequently wear it at all times throughout the 24-h test period except when in bed or when bathing or showering, when they were asked to place the monitor nearby in a vertical position. At the end of the 24-h period, the subjects were required to switch off the monitor and complete a questionnaire concerning activities and events during the collection period.

Workplace study — home and work assessments

The working subjects recruited for participation in cells 3 to 6 were provided with two personal monitors, one for use while at work and the other for use at all other times. The monitoring period commenced on arrival at the workplace, where the subjects were required to switch on the "work" monitor and wear it at all times throughout the work period. At the end of work, the subjects were required to switch off the "work" monitor and complete a questionnaire concerning activities and events during the collection period. They were then required to switch on the second "home" monitor and wear it for the remainder of the 24-h collection period. On reaching the workplace the following day, the subjects were required to switch off the "home" monitor and complete a questionnaire concerning activities and events during the collection period.

Final visit to the study center

Both the single monitor and dual monitor subjects were required to return to the study center to complete a "final-visit" questionnaire and provide a second saliva sample (postsample). The equipment and study documentation were then checked at the center by the study investigators. This procedure included checking the sampling flow rates and elapsed time indicators of the monitors.

Collection of saliva samples

Dental swabs sealed in hygienic vials (salivettes, Sarstedt, Leicester, England) were used to collect the saliva samples. By removing the lid and tilting the vial to the lips, the subjects could transfer the swab to the mouth without touching it. After chewing for a timed minute, the subjects returned the swab to the vial using the tongue. The cap was then replaced and the vial stored in a freezer (−20°C) until required for analysis. The subjects were asked to chew fairly vigorously for the timed minute to stimulate saliva production. This process was demonstrated in the video presentation.

Personal monitor

Exposures to RSP and ETS were assessed using a personal monitor designed to collect ETS particles and nicotine from the air close to the subject's breathing zone throughout a 24-h period as described by Ogden et al (17). The monitor consisted of a sampler head connected to a battery-operated pump (Airchek Model 50, SKC, South Appomattox, Virginia, United States) by a coiled polyurethane tube. The pump and disposable batteries were housed within a polypropylene dry-box containing polyurethane foam for protection and sound insulation. An adjustable shoulder strap was attached to the pump box, and the sampler head was worn in the breathing zone of the participant.

A diagrammatic representation of the sampler head is shown in figure 1. An important feature, emphasized in the video and in the training sessions, was to note that the red dot on the manifold should always be to the front and at the top. This was important in order that the air inlet for the cyclone would not be obstructed in any way and was always worn vertically.

RSP were collected using a model M00003700, 37 mm diameter, polystyrene filter holder (Millipore UK Ltd, Herts, England) containing a 1.0 µm pore size Fluoropore membrane filter (FALP 03700, Millipore UK Ltd, Herts, England) and a model 0300139-A31 gasket (Sloan Valve Co, Franklin Park, Illinois, United States). Particle size discrimination was achieved using a 10 mm Dorr-Oliver cyclone, designed to meet OSHA standards for RSP, mounted on the inlet side of the filter holder. The cyclone passes 50% of 3.5 µm particles and no particles $\geq$ 10 µm in size (18).

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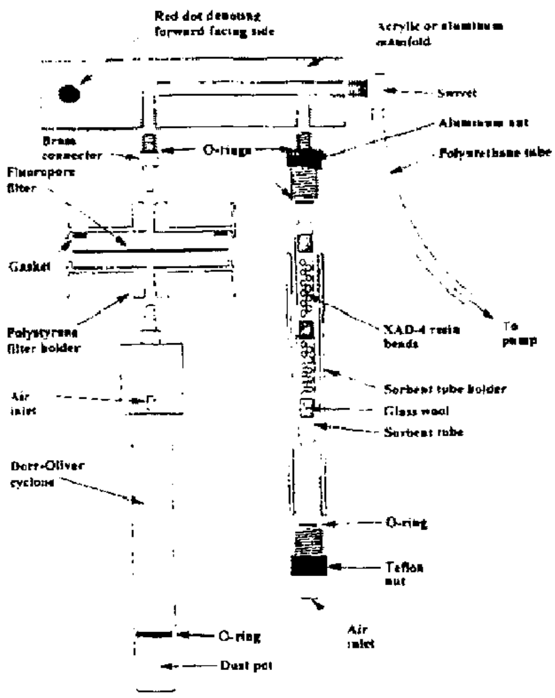

Figure 1. Diagrammatic representation of the personal monitor sampling head.

Vapor-phase nicotine and 3-ethenylpyridine were adsorbed onto XAD-4 resin beads contained within a glass-walled tube (SKC Ltd. Dorset, England). The beads were mounted within a polycarbonate tube holder attached to the sampler manifold.

The pump flow rate was set such that a flow rate of 1.72 $l \cdot min^{-1}$ ($\pm$0.02) for RSP and a nominal 0.8 $l \cdot min^{-1}$ for vapor-phase collection was achieved. An elapsed time indicator, actuated by vacuum, was provided for accurate determination of the total sampling time.

Assembled filter holders were sealed with shrink-wrap security bands to deter tampering, and sealing caps were used to exclude air from the filter holders prior to and after the sampling period. XAD-4 tubes were supplied heat sealed, the ends being snapped open prior to use and sealed with caps after the sampling. The capped XAD-4 tubes and assembled filter holders were stored frozen (−20°C) until required for analysis.

Analytical procedures

Respirable suspended particles

RSP were trapped on the Fluoropore filter in the personal monitor. The weight collected was determined to the nearest microgram by weighing the filter before and after the monitoring period. A radioactive static eliminator (PDV-1, Amersham International plc, England) was used during the weighing to maintain good precision. The filters, both pre- and postsampling, were also maintained in a controlled environment (temperature 21°C, relative humidity 50%) for at least 12 h prior to being weighed.

Contribution of environmental tobacco smoke to respirable suspended particles

Ultraviolet (UV), fluorescence, and solanesol measurements were used to estimate the contribution of ETS to the total quantity of particles collected by the Fluoropore filter of the personal monitor. The use of these three methods has been discussed by Ogden et al (19).

For the UV and fluorescence measurements, the particles were extracted from the Fluoropore filter with methanol. An aliquot of the extract was injected into a columnless high-performance liquid chromatography (HPLC) system and passed through a UV detector (325 nm) and a fluorescence detector (excitation 300 nm, emission 420 nm) in series. The peak areas of the UV and fluorescent signals obtained were calibrated against surrogate standards, and the quantities of ETS particles in the extract were estimated using predetermined conversion factors (14).

Throughout the study surrogate standards of 2,2',4,4'-tetrahydroxybenzophenone (THBP) and scopoletin were used for calibrating the UV and fluorescence measurements, respectively.

The solanesol content of the methanol extract was determined by reverse phase HPLC using methanol as the mobile phase and UV detection at 210 nm. The quantity of solanesol present in the extract was converted to a quantity of ETS particles using a predetermined factor (14).

The ETS particles determined by the UV and fluorescence methods are commonly referred to as UVPM and FPM, respectively. The ETS particles determined by the solanesol method are referred to as SolPM in this paper.

The factors used to convert the UV, fluorescence, and solanesol measurements into weights of ETS particles were established by experiments in a model room. ETS was generated by humans smoking combinations of cigarettes typically found in the United Kingdom (five best-selling brands), and ETS particles were collected from the model room atmosphere with personal monitors. A range of particle weights for ETS was collected on the personal monitor filters by varying the sampling time. The UV absorption, fluorescence, and solanesol contents were measured, and the relationship with the weight of the particles was determined. These factors, as used by Phillips et al (14), were determined using cigarettes retailed in the United Kingdom and consequently

may differ from factors determined using Swedish cigarettes, should they be investigated. However, it is not considered that such differences would significantly affect the results of this investigation. The factors obtained were similar to those reported by Ogden et al (19) for cigarettes from the United States.

Nicotine and 3-ethenylpyridine

Nicotine and 3-ethenylpyridine were extracted from XAD-4 resin with ethyl acetate containing triethylamine (0.01% by volume) to prevent adsorption of the analytes by glassware. Quinoline was added as an internal standard. Nicotine and 3-ethenylpyridine were quantified using capillary gas chromatography with thermionic specific detection.

Saliva cotinine

Salivettes containing saliva samples were thawed and then centrifuged to release the saliva from the cotton swab. The cotinine concentrations were then quantified using radioimmunoassay in the form of a kit supplied by the Department of Biochemistry, Brandeis University, Massachusetts, United States. The samples were incubated with anticotinine antiserum and ^{3}H-cotinine, and the bound fraction was subsequently separated using a second antibody followed by centrifugation. The amounts of radioactivity in the resulting precipitates were determined using a liquid scintillation counter. The method is based upon that of Van Vunakis et al (20).

Limits of quantification for all the analytes

The methods used to determine UVPM, FPM, SolPM, nicotine, 3-ethenylpyridine, and cotinine were validated. Each validation was performed by assaying batches containing samples suitable for the assessment of specificity, sensitivity, precision, accuracy, response function, recovery, and stability. The limits of quantification (LOQ) were determined for the analytes as the lowest concentrations for which precision and accuracy, both within each batch and between batches, did not exceed ± 20%.

With the exception of cotinine, when the LOQ are expressed in terms of air concentrations, the volumes of air drawn through each filter and sorbent tube must be taken into account and, for UVPM, FPM and SolPM, the application of conversion factors is needed for calculating particle concentrations of ETS. With each monitor operating for different durations (especially during the dual monitor study) and with slight variations in flow rates, the LOQ were different for each sample taken.

Fluoropore filter blanks were prepared throughout the study by attaching the filter holder to the sampler head and adjusting the flow to the required rate. The filter holders were then removed from the sampler head, capped, and stored frozen awaiting analysis. The mean weight change of the filter blanks prepared during the study was 5.77 µg with a standard deviation of 7.21 µg. A weight change of the mean plus two standard deviations (20.2 µg) was considered real and measurable for a subject's filter. This weight change was then used as the analytical LOQ.

Table 2. Limits of quantification for the analytical methods according to collection period. (ETS = environmental tobacco smoke)

Measurement	Collection period		
	24 h	15.3 h[a]	7 3 h[b]
Respirable suspended particles (RSP)	8 16 $\mu g \cdot m^{-3}$	12.8 $\mu g \cdot m^{-3}$	26.8 $\mu g \cdot m^{-3}$
ETS particles measured by ultraviolet light (UVPM)	0.37 $\mu g \cdot m^{-3}$	0.58 $\mu g \cdot m^{-3}$	1.21 $\mu g \cdot m^{-3}$
ETS particles measured by fluorescence (FPM)	0.06 $\mu g \cdot m^{-3}$	0.09 $\mu g \cdot m^{-3}$	0.19 $\mu g \cdot m^{-3}$
ETS particles measured by solanesol (SolPM)	0.23 $\mu g \cdot m^{-3}$	0.37 $\mu g \cdot m^{-3}$	0.77 $\mu g \cdot m^{-3}$
Nicotine	0.09 $\mu g \cdot m^{-3}$	0.14 $\mu g \cdot m^{-3}$	0.29 $\mu g \cdot m^{-3}$
3-Ethenylpyridine	0.09 $\mu g \cdot m^{-3}$	0.14 $\mu g \cdot m^{-3}$	0.29 $\mu g \cdot m^{-3}$
Saliva cotinine	0.50 $ng \cdot ml^{-1}$		

[a] Mean time spent outside the workplace for the working subjects in Stockholm.
[b] Mean time spent in the workplace for the working subjects in Stockholm.

Table 2 presents the LOQ in terms of air concentrations for the analytical methods based upon the sample collection periods. The limits established for RSP were similar to those found by other investigators (21—23). They assume filter and sorbent tube flow rates of exactly 1.72 and 0.800 $l \cdot min^{-1}$, respectively.

For many of the analyses, the levels found were below the LOQ. This finding raises the question of how to deal with these results in the calculation of the means, medians, and other parameters in the data analysis. If a value of zero had been applied when the results were below the LOQ, the average exposure would have been underestimated. Conversely, if the value ascribed to the LOQ had been applied in such cases, then the average exposure would have been overestimated. As a reasonable compromise, a value of one-half of the LOQ was used for the data analysis. The same compromise has been used in other studies of this type (14, 24).

Subjects selected for the study

One hundred and ninety persons claiming to be nonsmokers were recruited as volunteers for the study, but three subjects were excluded because they admitted to being smokers on the "first-visit" questionnaire. This

change took place after they watched the video, although they had claimed nonsmoking status in their initial telephone contact by means of a screening questionnaire. This type of discordant answer, referred to by Wells (25), may be due to subjects being questioned at two different points in time. It could also be due to additional information being provided, in detail, thus making the subjects reconsider their response.

Another five subjects were excluded because their saliva cotinine levels were above the selected threshold for nonsmokers. For the remaining 182 subjects the age and gender distributions within each cell investigated are presented in table 3.

The single monitor study was specifically designed to estimate the ETS exposure of housewives who spend the majority of their time at home. In Stockholm, recruitment for this cell proved extremely difficult. Only about 2% of the population can be regarded as belonging to this category, and the term "housewife" itself is not commonly in use. In order to increase the cell count, "house-husbands" were also recruited into cells 1 and 2.

Two subjects falling outside the specified age ranges, one younger than 20 years and one older than 64 years, were also included in the study, both of which were in cell 2. In this way, much needed data on ETS exposure in the home could be obtained.

Table 3. Age and gender distribution of the study subjects.

Cell	Gender		Age range (years)				
	Females (N)	Males (N)	< 20	20—34	35—49	50—64	> 64
1	5	4	.	3	3	3	.
2	20	15	1	15	6	12	1
3	.	2	.	.	.	2	.
4	6	4		3	2	5	.
5	32	21	.	12	22	19	.
6	42	31		27	23	23	.
Total	105	77	1	60	56	64	1

Age and gender distribution

Table 3 shows a bias towards women of approximately 14%, but the spread of subjects by age group is close to that planned (33% per group).

Geodemographic distribution

The study was designed to have participating subjects representative of the population of Stockholm. Figure 2 shows that the participants of the study closely resembled the population as expressed by Mosaic life-styles. Therefore, there is no reason to believe that the study attracted a misproportion of people significantly different from that representing the total population of Stockholm. The population sectors contained within each Mosaic group are presented in table 4. Mosaic groups B and J did not exist in the target area for Stockholm and hence do not appear in figure 2.

Occupations

The participants were restricted to a choice of 12 occupations from which to select and provide their answers on the last-visit questionnaire. Table 5 lists these occupations and the answers that were provided by the 138 subjects who wore the workplace monitor in this study.

Misclassifiation or misreporting of smoking status

This study did not set out to investigate the misreporting of smoking status in any detail. Another study, run concurrently with this one, focused on misclassification and smoking history and will be the subject of a detailed publication in the future.

The debate goes on regarding the use of cotinine as a marker for ETS exposure and for discriminating between smokers and nonsmokers. We decided to use saliva cotinine measurements as a guide for smoking status but not

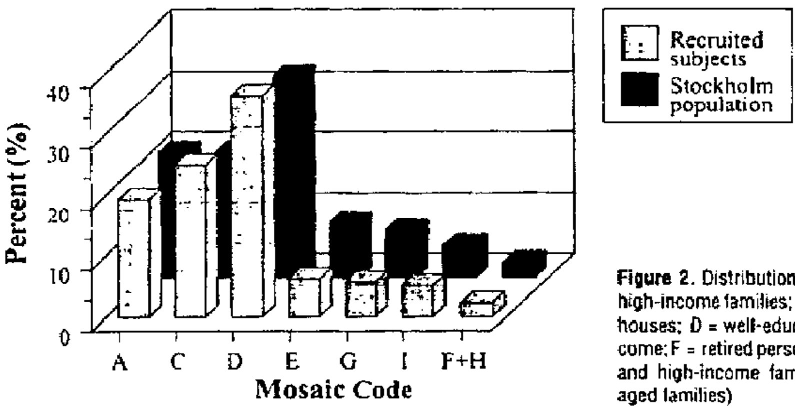

Figure 2. Distribution of the subjects' life-styles. (A = well-educated high-income families; C = persons with low and middle income, rented houses; D = well-educated in big cities; E = young persons, low income; F = retired persons; G = families with small children; H = middle- and high-income families, own villas/detached houses; I = middle-aged families)

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as an absolute marker for ETS exposure. Jarvis et al (26) concluded that cotinine is the marker of choice for smoking status and that saliva gives essentially the same information as blood samples. Curvall et al (27) also suggested that saliva concentrations give the same information about cotinine disposition in the body as do plasma concentrations.

Again, in order to determine whether the subjects had misreported their smoking status, a threshold limit had to be used. Etzel's review (16) indicated that subjects with saliva cotinine levels between 10 and 100 ng · ml^{-1} have been classified as infrequent smokers or regular smokers with low-level nicotine intake. Subjects with levels greater than 100 ng · ml^{-1} have been regarded as regular smokers. Previously this author (14) had chosen 25 ng · ml^{-1} to avoid any possibility of heavily exposed nonsmokers being incorrectly categorized as smokers. This was the threshold concentration used for this study.

It is interesting to note that, of the three subjects admitting to being smokers by means of questionnaire responses, two were not identified as smokers by their saliva cotinine measurements, neither having concentrations in excess of 0.9 ng · ml^{-1}. This finding may demonstrate that saliva cotinine measurements can fail to identify occasional smokers who have not smoked for a few days and could thus underestimate the extent to which smokers describe themselves as nonsmokers. The remaining subject had a saliva cotinine level of 438 ng · ml^{-1} indicative of a regular smoker.

Rejected subjects

The number of subjects that would have been rejected as smokers at different threshold levels is shown in table 6. Clearly saliva cotinine concentrations between 15 and 30 ng · ml^{-1} give the same number of rejected subjects, although the selection of a threshold level within the range 10—50 ng · ml^{-1} was not considered critical. Depending upon the criteria used, which included responses to questionnaires, the rate at which the recruited subjects misreported their smoking status varied. The values ranged from 2.7 (5 from 187)% to 5.3 (10 from 190)%.

Weather conditions during the study

Detailed information about the weather conditions and the levels of certain airborne pollutants during the course of the study was obtained from the local environmental office in Stockholm (Miljöförvaltningen, Box 38024, S-100 64, Stockholm). The study was carried out during November and December 1994 with hourly mean temperatures over this period varying from a minimum of −1.5°C to a maximum of 12.1°C. A maximum daily rainfall of 16 mm was recorded, with rain falling on 3 d of the three-week period. The windspeeds varied between 0.4 and 9.9 m · s^{-1}, and the maximum and minimum relative humidities of 98.7% and 46.3%, respectively, were recorded.

Concentrations of airborne pollutants, namely, nitrogen oxides (NO_x), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO), were measured during the study period at specific monitoring stations

Table 4. Population sectors contained within the Mosaic groups.

Mosaic code	Population sectors
A	Well-educated, high-income families
B	Middle-income families in industrial areas
C	Persons with low and middle income, rented houses
D	Well-educated in big cities
E	Young persons, low income
F	Retired persons
G	Families with small children
H	Middle- and high-income families, own villas/detached houses
I	Middle-aged families
J	Countryside and farming

Table 5. Occupations of the recruited subjects.

Occupation	Number of responses
Administration	35
Building trade	3
Education	18
Engineering	3
Government	15
Legal	7
Medical	12
Other	22
Retail	7
Science	11
Transport	4
Leisure	1
Total	138

Table 6. Number of subjects classified as smokers as a function of the saliva cotinine rejection threshold.

Cut-off level[a] (ng · ml^{-1})	Subjects rejected (N)
10 Etzel 1990 (16)	8
15 McNeill 1987 (36)	7
25 This study, also Phillips 1994 (14)	7
30 Lee 1987 (37)	7
50	6
100	5

[a] Also listed, are the references from which the cut-off level was taken

within Stockholm. Data were provided from the following three different locations:

- Kanaan — a background station located in a recreational area
- Torkel Knutssongatan — inner city location at roof level (height 20 m)
- Hornsgatan — inner city location at street level (height 3 m).

The ranges of the concentrations measured for each pollutant are presented in table 7 according to the mean hourly measurements at each monitoring station. The variations in the daily mean concentrations of NO_2 over the study period are presented in figure 3. The air quality bandings used in the United Kingdom to describe air quality are also depicted in this figure.

Table 7. Concentration ranges of the airborne pollutants ($\mu g \cdot m^{-3}$) determined at the Kanaan, Torkel Knutssongatan, and Hornsgatan monitoring stations throughout the study period.

Analyte	Kanaan	Torkel	Hornsgatan
Nitrogen oxides	0.2—83.0	0.0—528.6	9.0—1255.8
Nitrogen dioxide	0.0—52.0	1.7—70.1	5.3—111.4
Sulfur dioxide	0.0—35.1	0.0—34.7	.
Carbon monoxide	.	.	0.2—7.9

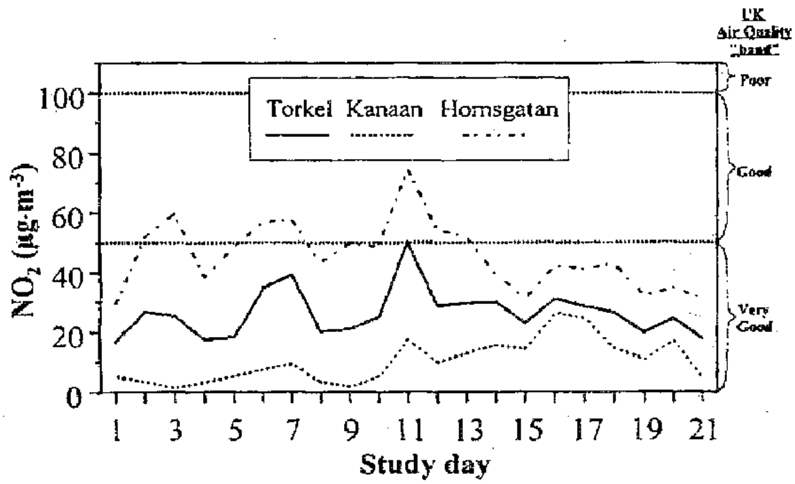

Figure 3. Atmospheric pollutants, mean daily levels, nitrogen dioxide (NO_2).

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Results and discussion

Comparison of overall exposures between the housewives and househusbands and the working subjects

In the reporting of the results, both the mean and the median values of each data set have been quoted together with their range of values. In this type of study, where the results are far from being normally distributed, the median is a more appropriate measure than the mean, as one or two exceptionally high values may have a disproportionately large effect upon the mean when most of the other values are relatively low.

Tables 8 and 9 show the summary analytical data for all the subjects from the home (single monitor) and workplace (dual monitor) studies, respectively. These tables exclude the subjects who admitted to being smokers and the subjects who were classified as likely smokers according to their saliva cotinine measurements. The results from the subjects with high saliva cotinine levels due to snus, an orally absorbed tobacco product, or gum use have been included.

With cells 1 and 2 combined, the median level of RSP for home exposure was 22 $\mu g \cdot m^{-3}$ with an ETS contribution based on an SolPM of 0.23 $\mu g \cdot m^{-3}$. Similarly, for the home exposure portion of the workplace study, the median RSP exposure was 19 $\mu g \cdot m^{-3}$ with an ETS contribution based on a SolPM of 0.21 $\mu g \cdot m^{-3}$. For the workplace, the median exposure to RSP was 16 $\mu g \cdot m^{-3}$ with a contribution from ETS of 0.5 $\mu g \cdot m^{-3}$.

In table 8 the ETS particle exposures calculated using medians show the trend UVPM > FPM > SolPM. These findings are consistent with those of Ogden et al (19), who concluded that both UVPM and FPM measurements may overestimate the contribution of ETS to RSP. Solanesol, as a true tobacco-specific marker, was used throughout this study to determine ETS. However solanesol is more difficult to measure, more than 60% of the data falling below the LOQ in this study.

It should be noted that the median concentrations of nicotine and 3-ethenylpyridine for both the single and dual monitor studies were comparable, below their LOQ. For ease of comparison with previous publications, nicotine concentrations have been reported in this study. This does not and should not preclude the use of 3-ethenylpyridine as a marker for exposure to ETS in the future, but in this study nearly 75% of the data for this analyte fell below the LOQ.

The median exposure values reported in tables 8 and 9 are close to or below the LOQ for the methods used. This result is consistent with the subjective assessments for the single monitor home study, in which about 80% of the subjects considered their exposure to ETS over the sampling period as "none" or "low." The subjective assessments were performed twice, once immediately at

Table 8. Summary statistics for all the analytes for the housewives and househusbands from smoking and nonsmoking homes, single monitor study. (RSP = respirable suspended particles, UVPM = particles of environmental tobacco smoke measured by the ultraviolet light method, FPM = particles of environmental tobacco smoke measured by the fluorescence method, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
Cotinine ($ng \cdot ml^{-1}$), premonitoring samples	44	1.2	0.68	0.25—5.6
Cotinine ($ng \cdot ml^{-1}$), postmonitoring samples	43	1.4	0.73	0.25—11
RSP ($\mu g \cdot m^{-3}$)	40	29	22	6.2—154
UVPM ($\mu g \cdot m^{-3}$)	40	5.2	0.85	0.18—84
FPM ($\mu g \cdot m^{-3}$)	38	3.3	0.44	0.03—71
SolPM ($\mu g \cdot m^{-3}$)	40	7.4	0.23	0.11—104
Nicotine ($\mu g \cdot m^{-3}$)	42	0.92	0.05	0.04—7.5
3-Ethenylpyridine ($\mu g \cdot m^{-3}$)	42	0.24	0.05	0.04—1.8

Table 9. Summary statistics for all the analytes for the working subjects in all the environments, dual monitor study. (RSP = respirable suspended particles, UVPM = particles of environmental tobacco smoke measured by the ultraviolet light method, FPM = particles of environmental tobacco smoke measured by the fluorescence method, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
Cotinine ($ng \cdot ml^{-1}$), premonitoring samples	133	3.5	0.55	0.25—362
Cotinine ($ng \cdot ml^{-1}$), postmonitoring samples	135	3.6	0.25	0.25—391
Home monitor				
RSP ($\mu g \cdot m^{-3}$)	129	21	19	4.8—89
UVPM ($\mu g \cdot m^{-3}$)	129	1.8	0.73	0.21—44
FPM ($\mu g \cdot m^{-3}$)	128	1.3	0.53	0.04—33
SolPM ($\mu g \cdot m^{-3}$)	129	2.1	0.21	0.13—65
Nicotine ($\mu g \cdot m^{-3}$)	129	0.20	0.08	0.05—9.3
3-Ethenylpyridine ($\mu g \cdot m^{-3}$)	129	0.12	0.07	0.05—2.8
Work monitor				
RSP ($\mu g \cdot m^{-3}$)	135	24	16	9.4—96
UVPM ($\mu g \cdot m^{-3}$)	134	2.0	0.81	0.40—22
FPM ($\mu g \cdot m^{-3}$)	135	1.3	0.66	0.06—15
SolPM ($\mu g \cdot m^{-3}$)	135	2.2	0.50	0.25—49
Nicotine ($\mu g \cdot m^{-3}$)	134	0.33	0.17	0.10—3.1
3-Ethenylpyridine ($\mu g \cdot m^{-3}$)	134	0.22	0.16	0.10—1.3

the end of the sampling period and again when the monitors were returned to the study center. Both results are depicted in figure 4.

For the dual monitor study similar assessments were made by questionnaire for both the home and work environments. For the home there was a difference in the answers provided by the subjects who indicated their exposure was "none" from 90% in the postsampling questionnaire to ≈ 60% in the last-visit survey. Therefore about 75% of the subjects indicated their home exposure to ETS to be "none" or "very low" (figure 5). Figure 6 shows a similar response for the workplace.

Figure 7 shows the distribution of SolPM for the single monitor and dual monitor studies. In the case of the single monitor subjects, 60% had exposures to ETS of 1 $\mu g \cdot m^{-3}$ or less when based on SolPM. These expo-

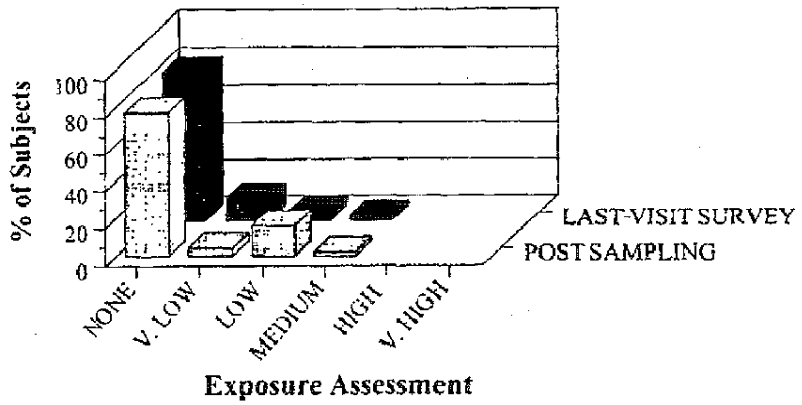

Figure 4. Subjective assessment of exposure to environmental tobacco smoke, single monitor study.

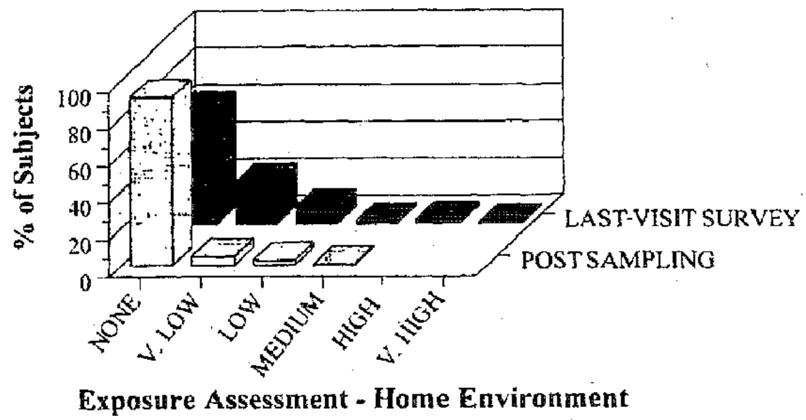

Figure 5. Subjective assessment of exposure to environmental tobacco smoke, dual monitor study (home environment).

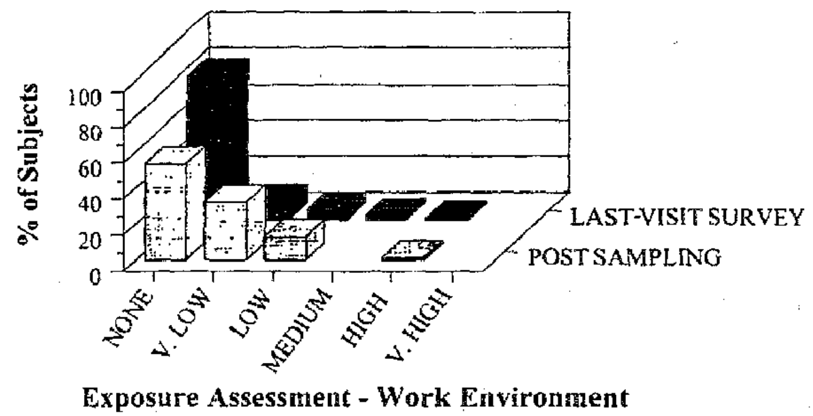

Figure 6. Subjective assessment of exposure to environmental tobacco smoke, dual monitor study (work environment).

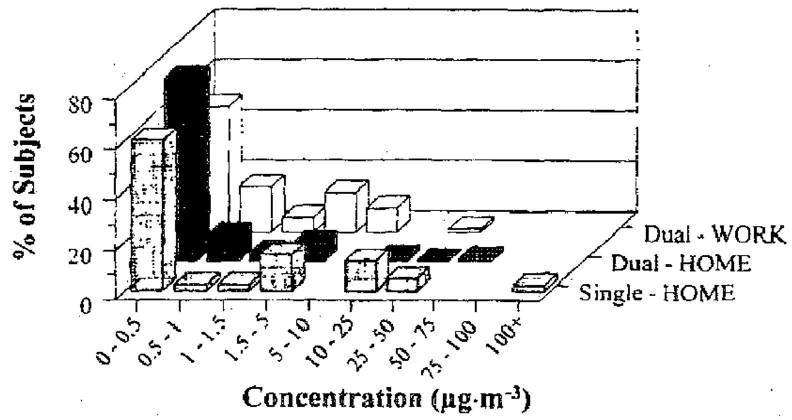

Figure 7. Distribution of the exposure concentrations of the particles of environmental tobacco smoke as measured by the solanesol method (all subjects).

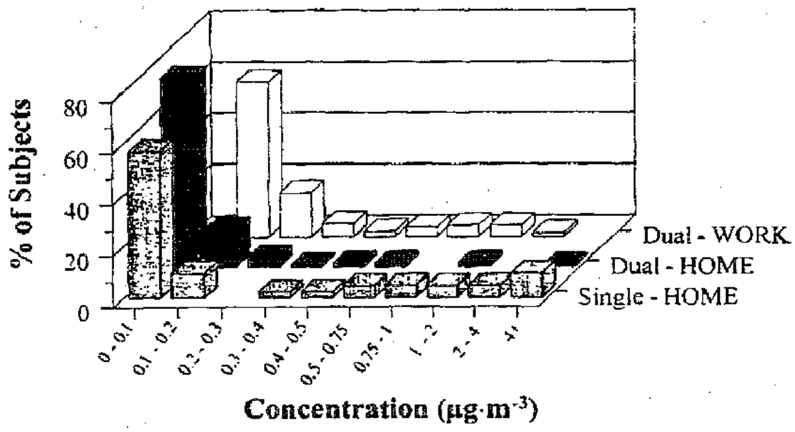

Figure 8. Distribution of the nicotine exposure concentrations (all subjects).

sure levels of < 1 µg · m^{-3} occurred for more than 80% of the subjects in the home in the dual monitor study. For the workplace more than 55% of the subjects had exposure levels between 0 and 1 µg · m^{-3}.

In the case of nicotine exposure (figure 8) more than 60% of the subjects in the single monitor home study had exposures between 0 and 0.2 µg · m^{-3}. These exposure levels of < 0.2 µg · m^{-3} were observed for more than 85% of the subjects at home in the dual monitor study. The majority of the subjects at work (75%) had exposure to nicotine between 0 and 0.3 µg · m^{-3}.

The levels measured for solanesol and nicotine were close to or below the LOQ of the methods.

Comparison of exposures for the housewives and househusbands in the single monitor study

Differences between smoking and nonsmoking households

Summary analytical results are presented by cell in table 10. The subjects living in smoking households were found to have higher median exposures to ETS particles and nicotine (17 µg · m^{-3} and 1.1 µg · m^{-3}, respectively) than those living in nonsmoking households (0.12 µg · m^{-3} and 0.05 µg · m^{-3}, respectively). The pre- and postsample cotinine median levels were also higher for the subjects in smoking households than in nonsmoking ones.

The levels of ETS (SolPM) for the housewives and househusbands living in smoking households were the highest measured in this study. The levels of SolPM and nicotine were at least 12 and 5 times higher, respectively, than in any other smoking or nonsmoking environment investigated. The corresponding median level for RSP was twofold higher for the smoking homes (39 µg · m^{-3}) than for the nonsmoking homes (18 µg · m^{-3}). This finding is consistent with the summary of field studies by Guerin et al (28), in which they indicate that RSP in smoking locations are typically a factor of 1.5 to 2 times greater than in nonsmoking locations. This highest median value of 39 µg · m^{-3} is at the low end of the RSP levels reported in the literature even if smoking was not taking place. In smoking indoor environments RSP would be expected to exceed 100 µg · m^{-3}.

With an assumed breathing rate of 10 l · min^{-1}, equivalent to 0.6 m^3 · h^{-1} (29), the housewives and househusbands exposed to the median levels found in this study for nonsmoking households would be exposed to about 95 mg of RSP, 0.6 mg of ETS particles, and about 0.3 mg of nicotine in a year. The corresponding exposures for persons residing in smoking households in this study were approximately 205 mg of RSP, 89 mg of ETS particles, and about 5.8 mg of nicotine in a year. Repace & Lowrey (30) found levels of exposure among typical nonsmokers that were approximately 10 times higher than for the housewives and househusbands who resided in smoking households. These people were the most exposed subjects in the study.

These calculations were based on the assumption that the subjects were exposed to these median levels throughout the year. For comparison, a typical Swedish cigarette delivers about 10 mg of particles and 0.9 mg of nicotine to the smoker. In perspective, housewives and househusbands living in nonsmoking households would be exposed to less than one cigarette equivalent per year compared with between six and nine cigarette equivalents for those living in smoking homes.

Table 10. Summary statistics for the analytes measured directly for all the housewives and househusbands by smoking environment, single monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte[a]	Number of samples	Mean	Median	Range
Cotinine (ng · ml^{-1}), premonitoring samples				
Cell 1	9	3.1	2.9	0.75—5.6
Cell 2	35	0.71	0.56	0.25—4.7
Both	44	1.2	0.68	0.25—5.6
Cotinine (ng · ml^{-1}), postmonitoring samples				
Cell 1	9	3.8	2.9	0.53—11
Cell 2	34	0.75	0.41	0.25—3.9
Both	43	1.4	0.73	0.25—11
RSP (µg · m^{-3})				
Cell 1	9	51	39	15—154
Cell 2	31	22	18	8.2—58
Both	40	29	22	8.2—154
SolPM (µg · m^{-3})				
Cell 1	9	27	17	0.37—104
Cell 2	31	1.9	0.12	0.11—39
Both	40	7.4	0.23	0.11—104
Nicotine (µg · m^{-3})				
Cell 1	9	3.1	1.1	0.17—7.5
Cell 2	33	0.34	0.05	0.04—3.2
Both	42	0.92	0.05	0.04—7.5

[a] Cell 1 – smoking household, cell 2 — nonsmoking household.

Table 11. Summary statistics for the analytes measured directly for all the housewives and househusbands by gender, single monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
Cotinine (ng · ml^{-1}), premonitoring samples				
Men	19	1.3	0.68	0.25—4.7
Women	25	1.1	0.67	0.25—5.6
Cotinine (ng · ml^{-1}), postmonitoring samples				
Men	19	1.2	0.87	0.25—3.9
Women	24	1.5	0.39	0.25—11
RSP (µg · m^{-3})				
Men	17	29	18	8.2—154
Women	23	28	22	13—58
SolPM (µg · m^{-3})				
Men	17	11	0.45	0.12—104
Women	23	4.9	0.12	0.11—45
Nicotine (µg · m^{-3})				
Men	17	0.67	0.05	0.04—6.4
Women	25	1.1	0.05	0.04—7.5

Exposure difference by age and gender

Summary analytical results are presented in tables 11 and 12 by gender and age, respectively. There was no apparent difference in the median exposures to RSP and nicotine between the male and female subjects. For ETS, the exposures were 0.45 µg · m^{-3} for the men and below the LOQ (0.23 µg · m^{-3}) for the women.

Table 12. Summary statistics for the analytes measured directly for all the housewives and househusbands by age, single monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
Cotinine (ng · ml^{-1}), premonitoring samples				
20- to 34-year-old group	18	1.1	0.63	0.25—3.8
35- to 49-year-old group	9	1.9	0.68	0.25—5.6
50- to 64-year-old group	15	0.98	0.60	0.25—2.9
Cotinine (ng · ml^{-1}), postmonitoring samples				
20- to 34-year-old group	18	1.2	0.25	0.25—8.1
35- to 49-year-old group	8	2.4	0.76	0.25—11
50- to 64-year-old group	15	1.1	0.87	0.25—3.0
RSP (µg · m^{-3})				
20- to 34-year-old group	16	33	19	11—154
35- to 49-year-old group	8	31	27	8.2—58
50- to 64-year-old group	14	23	20	9.7—53
SolPM (µg · m^{-3})				
20- to 34-year-old group	16	8.5	0.13	0.11—104
35- to 49-year-old group	8	14	6.7	0.12—45
50- to 64-year-old group	14	3.1	0.12	0.12—19
Nicotine (µg · m^{-3})				
20- to 34-year-old group	17	0.96	0.05	0.04—6.4
35- to 49-year-old group	8	1.9	0.71	0.04—7.5
50- to 64-year-old group	15	0.27	0.05	0.04—0.96

However, when the results were summarized in accordance with age range (table 12), it was apparent that recruited subjects between 35 and 49 years of age were more highly exposed to ETS particles and nicotine. The median levels of ETS particles and nicotine observed for these subjects were at least sevenfold higher than those apparent for subjects in the age ranges of 20—34 and 50—64 years. The saliva cotinine levels were not indicative of the same trend, a finding not dissimilar to those of other studies that have provided evidence for the variable correlations of nicotine exposure with saliva cotinine levels (31).

Comparison of exposures of the working subjects at home and at work in the dual monitor study

In Stockholm, during the course of recruitment, it became apparent that the number of smoking homes available for study was extremely low. This situation was reflected by the poor recruitment of subjects into cells 3 and 4. Only 4.4% and 33% of the targeted numbers for cells 3 and 4, respectively, were recruited. As a consequence, a comparison of data to provide meaningful statistical analysis between individual cells was not advisable because of the inadequate numbers in these poorly recruited cells. Hence the cell data have been combined to provide summary analytical results according to smoking or nonsmoking environments. These are presented in table 13 for the home and table 14 for the workplace. In this instance comparison of the cotinine levels between the environments was not possible due to the combination of cells to provide "environment" information.

The median levels of nicotine and ETS particles were found to be higher for smoking environments both in the home and in the workplace with very little difference apparent for RSP. The highest median concentration of ETS particles (1.4 $\mu g \cdot m^{-3}$) was found for the smoking homes and was at least four times that of the nonsmoking homes. This value of 1.4 $\mu g \cdot m^{-3}$ equates to a home exposure of 0.01 mg per day based upon a mean time of 15.3 h spent in this environment. However, this level of exposure is substantially less than that found for the housewives and househusbands living in smoking homes (17 $\mu g \cdot m^{-3}$), which equates to an exposure of 0.24 mg per day. These ETS particle concentrations are also somewhat less than those of between 1.4 and 14 mg per day quoted by Repace & Lowrey (32), but they are much closer to those of Holcomb (33) (ie, between 0.06 and 0.1 mg per day, calculated from literature values for concentrations of ETS).

The corresponding nicotine levels in the homes of the working subjects were higher for the smoking environments (0.15 $\mu g \cdot m^{-3}$) than for the nonsmoking environments (0.07 $\mu g \cdot m^{-3}$). Again these levels were lower than those found for the housewives and househusbands living in smoking homes (0.15 $\mu g \cdot m^{-3}$ versus 1.1 $\mu g \cdot m^{-3}$) and considerably lower than the average exposure level of 1.63 $\mu g \cdot m^{-3}$ reported by Ogden et al (34) for employed subjects living in smoking households in the United States. There is a limited availability of data concerning nicotine exposure in the home, but Leaderer & Hammond (35) quote a range of 0.1 to 9.4 $\mu g \cdot m^{-3}$ for smoking households. The levels of exposure to ETS particles and nicotine in the workplace were not considered to differ from those observed in the home. Corresponding yearly exposures calculated from the median

Table 13. Summary analytical statistics for all the working subjects by smoking environment, home measurements in the dual monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte[a]	Number of samples	Mean	Median	Range
RSP ($\mu g \cdot m^{-3}$)				
Cells 3 + 4	10	27	24	7.4—63
Cells 5 + 6	119	21	19	4.8—89
All cells	129	21	19	4.8—89
SolPM ($\mu g \cdot m^{-3}$)				
Cells 3 + 4	10	12	1.4	0.17—65
Cells 5 + 6	119	1.3	0.20	0.13—56
All cells	129	2.1	0.21	0.13—65
Nicotine ($\mu g \cdot m^{-3}$)				
Cells 3 + 4	10	0.30	0.15	0.07—1.6
Cells 5 + 6	119	0.19	0.07	0.05—9.3
All cells	129	0.20	0.08	0.05—9.3

[a] Cells 3 & 4 = smoking households, cells 5 & 6 = nonsmoking households.

Table 14. Summary analytical statistics for all the working subjects by smoking environment, work measurements in the dual monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte[a]	Number of samples	Mean	Median	Range
RSP ($\mu g \cdot m^{-3}$)				
Cells 3 + 5	53	24	16	9.7—70
Cells 4 + 6	82	23	16	9.4—96
All cells	135	24	16	9.4—96
SolPM ($\mu g \cdot m^{-3}$)				
Cells 3 + 5	53	3.6	1.1	0.28—49
Cells 4 + 6	82	1.2	0.42	0.25—9.6
All cells	135	2.2	0.50	0.25—49
Nicotine ($\mu g \cdot m^{-3}$)				
Cells 3 + 5	54	0.48	0.20	0.11—3.1
Cells 4 + 6	80	0.23	0.15	0.10—1.8
All cells	134	0.33	0.17	0.10—3.1

[a] Cells 3 & 5 = smoking workplaces, cells 4 & 6 = nonsmoking workplaces.

concentrations of RSP, ETS particles (SolPM), and nicotine are presented in table 15. These values were calculated on the assumption of a 35-h workweek and a 48-week workyear, with the remaining time at home. From this table exposure to nicotine and ETS particles appears to be three to five times greater in the home than at work. These calculations are based largely on data below the LOQ.

Table 15. Calculated annual exposures to environmental tobacco smoke (ETS) for the working subjects. (RSP = respirable suspended particles)

Environment	Annual exposure (mg)			Cigarette equivalents
	RSP	ETS particles	Nicotine	
Smoking home	102	5.9	0.64	0.6—0.7
Smoking work	16	1.1	0.20	0.1—0.2
Nonsmoking home	81	0.85	0.30	0.1—0.3
Nonsmoking work	16	0.42	0.15	0.04—0.2

Table 16. Summary analytical statistics for the saliva continine concentrations of all the working subjects by gender, dual monitoring study.

Analyte	Number of samples	Mean	Median	Range
Cotinine ($ng \cdot ml^{-1}$), premonitoring samples				
Men	55	0.95	0.69	0.25—3.6
Women	78	5.3	0.25	0.25—362[a]
Cotinine ($ng \cdot ml^{-1}$), postmonitoring samples				
Men	57	7.7	0.25	0.25—391[a]
Women	78	0.54	0.25	0.25—3.1

[a] High levels attributable to the subjects considered to be nonsmokers currently using snus/gum.

Table 17. Summary analytical statistics for all the working subjects by gender, home measurements in the dual monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
RSP ($\mu g \cdot m^{-3}$)				
Men	55	19	17	5.4—88
Women	74	23	21	4.8—89
SolPM ($\mu g \cdot m^{-3}$)				
Men	55	2.6	0.20	0.13—56
Women	74	1.8	0.21	0.15—65
Nicotine ($\mu g \cdot m^{-3}$)				
Men	54	0.30	0.08	0.05—9.3
Women	75	0.13	0.07	0.05—1.4

Comparison of the working subjects by age and gender distribution

Summary analytical results by age and gender are presented in tables 16 through to 21. When the men are compared with the women there appears to be little difference in their median saliva cotinine levels (table 16). All the levels are at the LOQ with the exception of those for male presample measurements at 0.69 $ng \cdot ml^{-1}$. In addition, there were no apparent differences between the male and female working subjects either at home (table 17) or at work (table 18) when their median exposures to RSP, ETS particles, or nicotine, which were all at or below the LOQ, are used for the comparison.

When the age ranges were compared, the prestudy measurements of cotinine were highest in the 20- to 34-year age range (table 19). The next highest exposure was in the 35- to 49-year age range. The median value for the oldest age range was below the LOQ. These differences in median saliva cotinine concentrations may

Table 18. Summary analytical statistics for all the working subjects by gender, work measurements in the dual monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
RSP ($\mu g \cdot m^{-3}$)				
Men	55	24	16	9.7—96
Women	80	23	16	9.4—89
SolPM ($\mu g \cdot m^{-3}$)				
Men	55	2.5	0.45	0.25—49
Women	80	1.9	0.53	0.27—31
Nicotine ($\mu g \cdot m^{-3}$)				
Men	55	0.36	0.16	0.11—3.1
Women	79	0.31	0.18	0.10—2.8

Table 19. Summary analytical statistics for the saliva continine concentrations of all the working subjects by age, dual monitor study.

Analyte	Number of samples	Mean	Median	Range
Cotinine ($ng \cdot ml^{-1}$), premonitoring samples				
20- to 34-year-old group	39	0.92	0.65	0.25—3.6
35- to 49-year-old group	46	8.6	0.54	0.25—362[a]
50- to 64-year-old group	48	0.74	0.25	0.25—3.6
Cotinine ($ng \cdot ml^{-1}$), postmonitoring samples				
20- to 34-year-old group	41	0.78	0.25	0.25—5.4
35- to 49-year-old group	46	9.1	0.25	0.25—391[a]
50- to 64-year-old group	48	0.65	0.25	0.25—3.3

[a] High levels attributable to the subjects considered to be nonsmokers currently using snus/gum.

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be indicative of a higher exposure of the younger male working population of Stockholm to ETS.

Table 20 highlights the home situation with levels of exposure to ETS particles and nicotine, based on the median levels, all below their LOQ. The situation for the work environment is very similar (table 21), with no real differences between the age groups at work. There were no apparent differences between the levels of RSP, ETS particles, and nicotine between the work and home environments, all the median levels being at or below the LOQ.

Geodemographic comparisons of exposure to environmental tobacco smoke

Mosaic group

Although the numbers of subjects within each Mosaic group were not high enough to draw definite conclusions about trends in exposure to ETS, there was an indication that the nonworking subjects recruited from well-educated, high-income families (Mosaic group A) were more exposed to ETS than all the other population groups. Concentrations of ETS particles (7.7 $\mu g \cdot m^{-3}$) and nicotine (0.31 $\mu g \cdot m^{-3}$) were approximately seven and three times higher, respectively, than the next highest concentrations. There were no apparent differences between the Mosaic groups for the subjects who worked.

Income levels

As part of the last-visit survey, the subjects were required to indicate the level of monthly household income within stated earning brackets from SEK 10 000 or below, increasing to SEK 100 000 and above. As there were insufficient numbers in certain earning brackets to provide a comparison of ETS exposure with household income, several of the income brackets were combined. Summary statistics for the levels of exposure to ETS in the household income brackets of up to SEK 20 000, between SEK 20 000 and SEK 50 000 and above SEK 50 000 were calculated. Although definite conclusions could not be drawn from the data, there was an indication that workers from households with incomes in the lowest bracket may be exposed to higher levels of ETS.

Subjective comparisons of exposure to environmental tobacco smoke

The ETS exposures of individuals in smoking and nonsmoking environments have been extensively investigated as part of this study. However, it is interesting to note that information from the subjects' diaries, completed during the monitoring periods, and the last-visit survey questionnaires indicate that approximately 20% of all the subjects living or working in smoking environments did not see or smell any smoking during the monitoring period. Also apparent from this information was the fact that about 25% of all the subjects living or working in nonsmoking environments did note smoking during the monitoring period.

Table 20. Summary analytical statistics for all the working subjects by age, home measurements in the dual monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
RSP ($\mu g \cdot m^{-3}$)				
20- to 34-year-old group	41	26	22	4.8—89
35- to 49-year-old group	44	19	17	5.4—48
50- to 64-year-old group	44	20	17	5.9—63
SolPM ($\mu g \cdot m^{-3}$)				
20- to 34-year-old group	41	2.7	0.28	0.13—56
35- to 49-year-old group	44	1.1	0.19	0.15—17
50- to 64-year-old group	44	2.6	0.23	0.17—65
Nicotine ($\mu g \cdot m^{-3}$)				
20- to 34-year-old group	41	0.40	0.08	0.05—9.3
35- to 49-year-old group	46	0.09	0.07	0.05—0.38
50- to 64-year-old group	44	0.13	0.08	0.05—1.6

Table 21. Summary analytical statistics for all the working subjects by age, work measurements in the dual monitor study. (RSP = respirable suspended particles, SolPM = particles of environmental tobacco smoke measured by the solanesol method)

Analyte	Number of samples	Mean	Median	Range
RSP ($\mu g \cdot m^{-3}$)				
20- to 34-year-old group	42	25	16	10—96
35- to 49-year-old group	46	21	17	9.7—64
50- to 64-year-old group	47	24	15	9.4—89
SolPM ($\mu g \cdot m^{-3}$)				
20- to 34-year-old group	42	1.9	0.46	0.25—31
35- to 49-year-old group	46	3.0	0.54	0.28—49
50- to 64-year-old group	47	1.5	0.52	0.27—9.6
Nicotine ($\mu g \cdot m^{-3}$)				
20- to 34-year-old group	41	0.28	0.15	0.11—2.8
35- to 49-year-old group	45	0.37	0.21	0.11—1.8
50- to 64-year-old group	48	0.34	0.16	0.10—3.1

Single monitor study

The housewives and househusbands who lived in smoking homes and who reported the presence of smoking during their monitoring periods were exposed to more than five times the median levels of ETS particles (1.2 $\mu g \cdot m^{-3}$ versus 0.12 $\mu g \cdot m^{-3}$) and higher median levels of nicotine (0.15 $\mu g \cdot m^{-3}$ versus 0.05 $\mu g \cdot m^{-3}$) than those who did not report smoking. The concentration of RSP was also elevated (27 $\mu g \cdot m^{-3}$ versus 16 $\mu g \cdot m^{-3}$).

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Dual monitor study

The subjects who lived in smoking homes and who reported having seen or smelled tobacco smoke outside the workplace were again exposed to more ETS than those who did not. The median levels of ETS particles were about 16 times higher in this instance.

In the nonsmoking work and home environments, no appreciable differences between the median exposure to ETS particles and nicotine were apparent, whether smoking was or was not observed during the monitoring period. In the smoking work environments, as with the smoking home environments, exposure to ETS particles was higher for the subjects who noted smoking during the monitoring period than for those who did not ($1.6\ \mu g \cdot m^{-3}$ versus $0.46\ \mu g \cdot m^{-3}$). Similarly, the median nicotine concentrations were apparently elevated ($0.24\ \mu g \cdot m^{-3}$ versus $0.15\ \mu g\ m^{-3}$).

A nonsmoking workplace was defined by the absence of smoking co-workers within 30 m of a subject's workplace and was independent of any employer's smoking-nonsmoking policy. No account of the magnitude of smoking observed on any occasion was made in the calculation of these values.

Comparison of other measures of exposure to environmental tobacco smoke

Cotinine

Figure 9 shows the distribution of the pre- and postmonitoring cotinine saliva levels for all the subjects. Between 50% and 60% of all the subjects had levels between 0 and $0.75\ ng \cdot ml^{-1}$ in either their pre- or postsample. These results are comparable with the distribution of the SolPM exposures, which were between 0 and $1\ \mu g \cdot m^{-3}$ for at least 55% of all the subjects. These findings may indicate that cotinine is a suitable marker for exposure to ETS.

However, when the correlation between postcotinine and SolPM was compared, we found a poor fit, $R^2 = 0.337$ ($R^2 = 0.191$ with data below the LOQ removed). For FPM the correlation was even worse, $R^2 = 0.174$ ($R^2 = 0.130$ with data below the LOQ removed). The correlations between the nicotine and postmonitoring cotinine levels were slightly better with an R^2 value of 0.672 (0.552 with data below the LOQ removed). These findings again reinforce our previous suggestion that saliva cotinine measurements should not be used to assess exposure to ETS at low levels.

Solanesol

Using the solanesol (SolPM) method to estimate ETS exposure was considered to be more specific than the use of the UVPM and FPM methods. A comparison of the SolPM exposure concentrations with the FPM measurements gave a very good correlation ($R^2 = 0.824$). With all the data at or below the LOQ removed, the correlation was $R^2 = 0.815$ (figure 10). A similar value ($R^2 = 0.859$) for UVPM versus SolPM was apparent.

The best correlation of all was found when the UVPM values were compared with the FPM values when $R^2 = 0.98$ (figure 11).

Nicotine and 3-ethenylpyridine

Previous field studies summarized by Guerin et al (28) reported mean levels of nicotine below $10\ \mu g \cdot m^{-3}$. In this study nearly 75% of the subjects had nicotine exposures below the LOQ. Hence correlations with other methods of assessing exposure to ETS were not attempted.

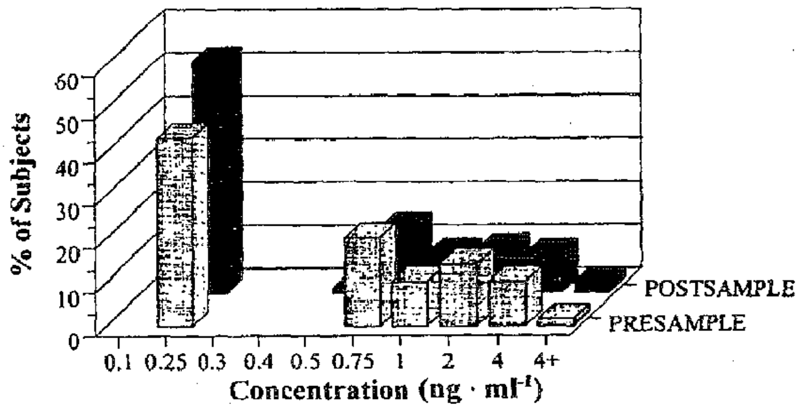

Figure 9. Distribution of the pre- and post-monitoring levels of cotinine in saliva, all subjects.

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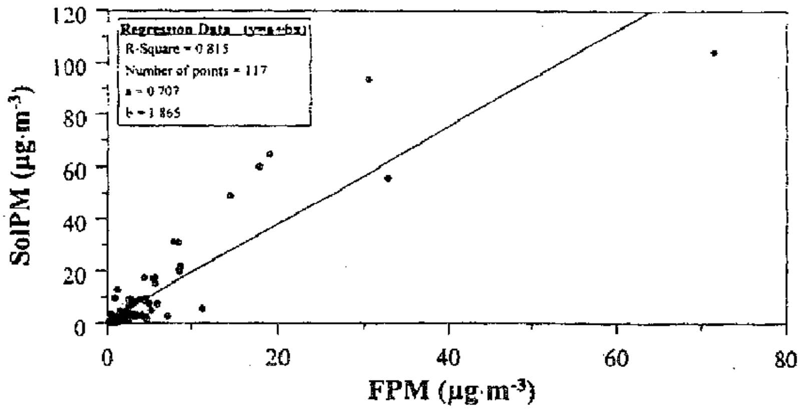

Figure 10. Correlation of the concentrations of particles of environmental tobacco smoke as measured with the fluorescence method with those measured by the solanesol method, using all data greater than the limits of quantification.

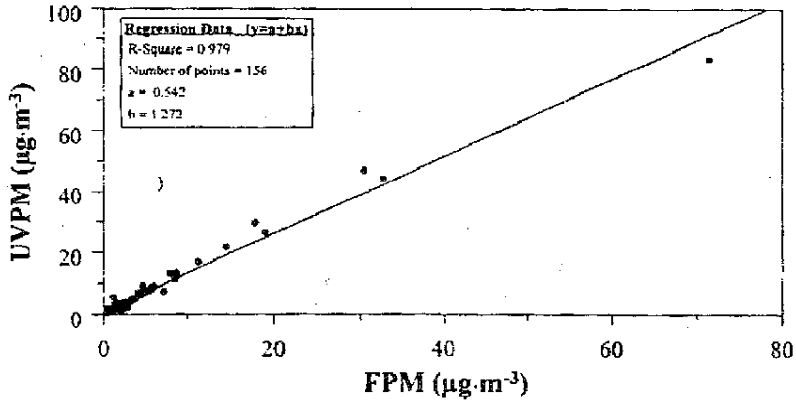

Figure 11. Correlation of the concentrations of particles of environmental tobacco smoke as measured with the fluorescence method with those measured by the ultraviolet method, using all data greater than the limits of quantification.

Concluding remarks

The geodemographic distribution of the subjects recruited for this study using the Mosaic system closely resembled that for the whole of Stockholm. The age and gender distributions of the subjects within this sample were acceptable. With a saliva cotinine threshold of 25 ng · ml^{-1}, misclassification rates of between 2.7% and 5.3% were apparent, depending on the criteria used.

For most of the subjects studied the exposures to ETS particles and nicotine were at or below the LOQ for the analytical methods used. The highest levels found were for the housewives and househusbands from smoking homes who were exposed to median concentrations of 39 µg · m^{-3} for RSP, 17 µg · m^{-3} for ETS particles, and 1.1 µg · m^{-3} for nicotine. The lowest levels found were for the workers in nonsmoking workplace environments where exposures to RSP, ETS particles, and nicotine were below the LOQ.

These levels equate to annualized exposures of 205 mg of RSP, 89 mg of ETS, and 5.8 mg of nicotine for the highest exposed housewives and househusbands and 16 mg of RSP, 0.42 of mg ETS particles, and 0.15 mg of nicotine for the workers in nonsmoking workplaces. In comparison with a typical Swedish cigarette, delivering about 10 mg of particles and 0.9 mg of nicotine to the smoker, these annualized exposures equate to between 6 and 9 cigarette equivalents for the highest exposed housewives and househusbands and between 0.04 and 0.2 cigarette equivalents for the workers in nonsmoking workplaces.

The annualized exposures for the workers living in smoking households were 102 mg of RSP, 5.9 mg of ETS particles, and 0.64 mg of nicotine, equivalent to between 0.6 and 0.7 cigarette equivalents. The corresponding exposures in smoking workplaces were 16 mg of RSP, 1.1 mg of ETS particles, and 0.2 mg of nicotine per year, equivalent to between 0.1 and 0.2 cigarette equivalents. These calculations would suggest that levels of exposure in the workplace are less than in the home.

More than 80% of all the housewives and househusbands considered their exposure to ETS as "none" or "low" during the 24-h period, and this evaluation was substantiated by the majority of measured levels being close to their LOQ.

For the working subjects in nonsmoking environments similar exposure levels were observed for the home and workplace, the measured levels being below the LOQ. The levels determined in the corresponding smoking environments were up to three times the LOQ.

For the housewives and househusbands living in smoking homes, the subjects with the highest exposure in this study, the median cotinine levels were 2.9 ng · ml^{-1} for both the pre- and postmeasurements. These were the highest median levels recorded, and, for the vast majority of the subjects in this study, cotinine was not a good marker for exposure to ETS. Overall, the median cotinine levels for the single monitor and dual monitor studies did not exceed 0.73 ng · ml^{-1}.

Nicotine exposure was extremely low for the housewives and househusbands at home, 60% of the subjects being exposed to less than 0.2 µg · m^{-3}. Similarly 85% of the workers, while at home, were exposed to less than 0.2 µg · m^{-3}. At work 75% of these subjects were exposed to less than 0.3 µg · m^{-3}.

The housewives and househusbands in the 35- to 49-year age range were up to sevenfold more exposed to ETS particles and nicotine than those in the other age ranges.

The levels of RSP in the work environments were nearly identical in both the smoking and nonsmoking workplaces. In the home, the concentration of RSP was 21% higher in the smoking, as opposed to the nonsmoking, environments (24 µg · m^{-3} versus 19 µg · m^{-3}), the difference being much less marked than for the housewives and househusbands living in smoking or nonsmoking homes (39 µg · m^{-3} versus 18 µg · m^{-3}). The maximum concentration of RSP measured was 154 µg · m^{-3} for a househusband in a smoking household. This value is only slightly higher than concentrations typically found (120 µg · m^{-3}) for indoor air where smoking takes place (17). The median levels for the highest exposed subjects in this study were significantly less than this value.

During the study period, the air quality in Stockholm was generally in the "very good" band according to air quality bandings used in the United Kingdom. For the remaining period the air quality could be classed as "good." The highest level of NO_2 occurred at street level on the day when the mean temperature fell to its lowest of −0.2°C.

As indicated by published field studies to date, the ETS exposures of the majority of the subjects in the Swedish study are among the lowest ever measured for a sizeable urban area.

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